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Fuel Cell Powered Unmanned Airvehicles – The Ion Tiger Program

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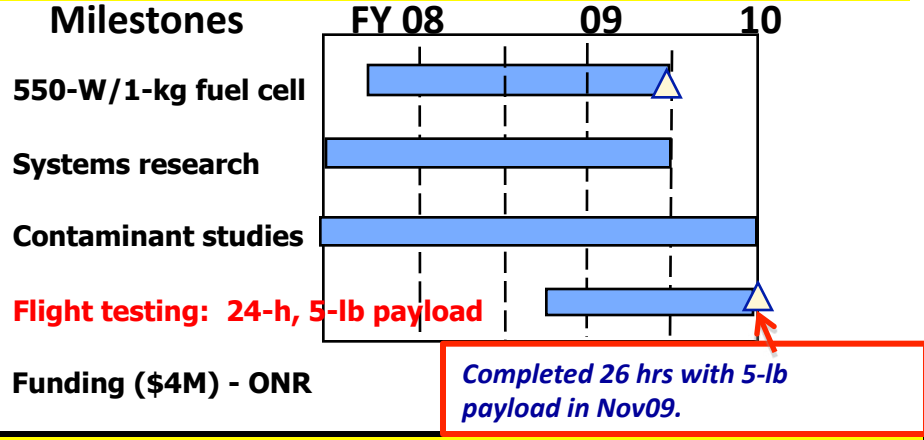
High Power Fuel Cell Propulsion Systems
Ion Tiger Program

Demonstrate 24 h flight of fuel cell powered UAV



Description

The Ion Tiger fuel cell UAV flies 24 hours with a 5 pound payload. The electric fuel-cell propulsion system is efficient, lightweight and quiet, providing a low-signature system for high-payoff missions. TRL= 6

Technology

- 35-pound UAV with 24-hour endurance and 5-pound payload capability.
- 550-W/ 1-kg polymer fuel cell system
- High capacity hydrogen fuel tanks (>12% storage)
- Fuel cell survivability and durability in naval conditions
- Operation in temperatures up to 120 °F

Goals & Benefits

- Alternative, electric propulsion system enables low altitude flights and Tier II missions with small UAV
- Benefits of Ion Tiger fuel cell UAV
  - long endurance = reduced CONOPS (launch 1x per day
  - quiet, low signature, easy start
  - 7x the capacity of batteries
  - produces only water and heat.
- Navy-owned technology

POCs: *Karen Swider Lyons, NRL, 202-404-3314*
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Motivation for High Power Fuel Cell Propulsion Systems

Fuel cell advantages:

- Higher energy than batteries
- Higher efficiency than engines
  Small engines ~10% efficient
  Fuel cells ~45% efficient

Benefit to Navy:

- Long endurance electric UAVs
- Quiet flights at 400 ft AGL with inexpensiv payload
  - Lowers cost and OPTEMPO of missions
- ***Big UAV missions with a small UAV***
  - "Nano-ization" of UAVs
  - Lower cost and maintenance
  - Less storage volume

Advantages of electric propulsion

- Near silent operation
- Instant starting
- Increased reliability
- Ease of power control
- Reduced thermal signature
- Reduced vibration

Energy of Fuel Cells vs. Batteries for Ion Tiger system

16 kg GTOW - 38 wt% fuel cell propulsion plant

- 6 kg fuel cell propulsion system (with fuel and cooling)
  = Specific energy of 1300 Wh/kg
  - 24 hours of flight at 300 W

- Compare to high energy Lithium battery
  = Specific energy of 200 Wh/kg
  - 4.8 hours of flight at 300 W from 6 kg of battery
  - OR 30 kg needed to fly for 24 hours at 300 W

Fuel Cell Propulsion Plant
ACCOMPLISHMENTS

- ✓ High power fuel cell (Protonex)
  - –Adapted higher-performance membranes, new humidifier, air water and water pumps
    - ⇒550 W in 1 kg
- ✓ High hydrogen fuel utilization (Protonex)
  - –Increased fuel utilization from 93 to 99%
- ✓ Customized fuel cell electronics (Protonex)
  - –Incorporated voltage cycling routines to improve fuel cell performance in flight
- ✓ High performance, lightweight radiator (NRL)
  - –Developed cooling model and validated It with wind tunnel testing
- ✓ Light hydrogen fuel storage tanks (NRL)
  - –Completed trade study to identify best method for hydrogen storage
  - –Implemented new methods to lighten aluminum liners
  - –Studying new materials to increase strength to weight ratio of carbon overwrap
- ✓ Poison recovery methods (NRL)
  - –Patented method to recover performance of contaminated fuel cells (NRL)
- ✓ System testing/validation (Hawaii)
  - –Developed protocols to map fuel cell performance over ranges of humidity and temperature

Design Sizing

TOGW	**35.5 lbs**
– *Fuel Cell*	*2.2 lb*
– *Fuel Tank*	*8.0 lb*
• *Fuel*	*1.1 lb*
– *Regulator*	*0.4 lb*
– *Cooling System*	*1.5 lb*
– *Propulsion System*	*0.9 lb*
– *Avionics*	*1.0 lb*
– *Airframe**	*15.5 lb*
– *Payload*	*5.0 lb*

*** With NRL supplied internal mounts, wiring, etc**

Dimensions

• Wing Area	16.9 ft^2
• Span	17.0 ft
• Aspect Ratio	17
• Length	7.9 ft
• L/D	17

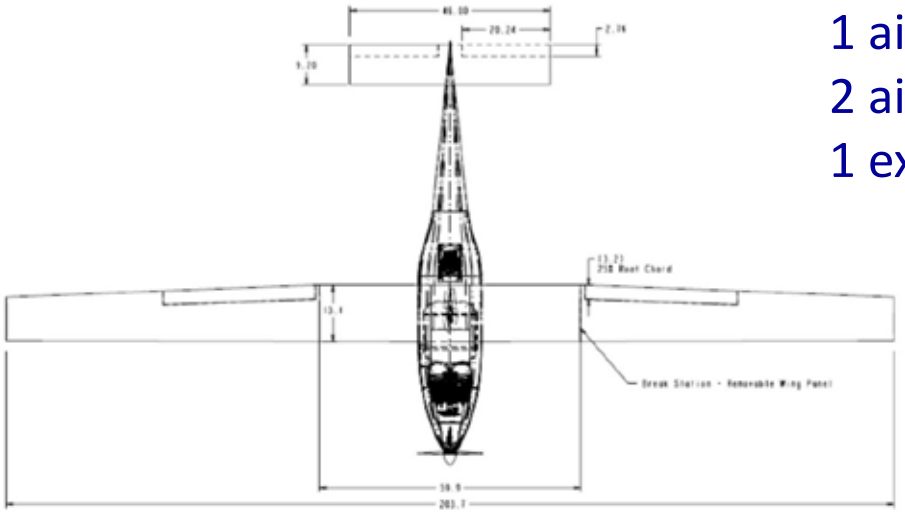
Cruise Power	**267w**
– *Propulsion*	*200 w*
– *Avionics*	*20 w*
– *Flight Controls*	*20 w*
– *Payload*	*20 w*
– *Conversion Losses*	*7 w*

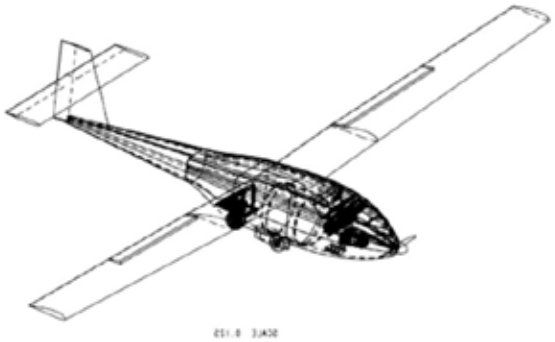
Attempts to identify a COTS airframe capable of carrying the fuel tank were unsuccessful, necessitating a custom airframe design.

Ion Tiger Airframe

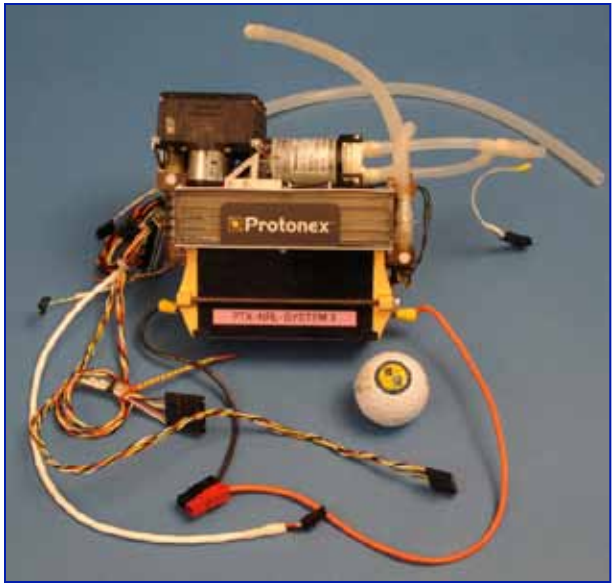
Designed and systems integration by NRL
Built by Arcturus UAV

- 1 airframe for battery test flights
- 2 airframes for fuel cell flights
- 1 extra nose for wind tunnel/thermal testing

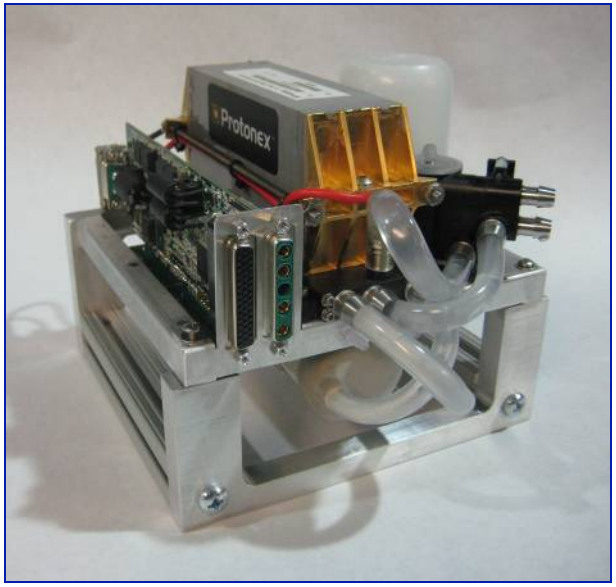




Progression of Fuel Cell Systems



Fuel cell at beginning of program (Fall 2007):
1 kg and 300 W net



Ion Tiger Program Product:

- ***1 kg and 550 W net***

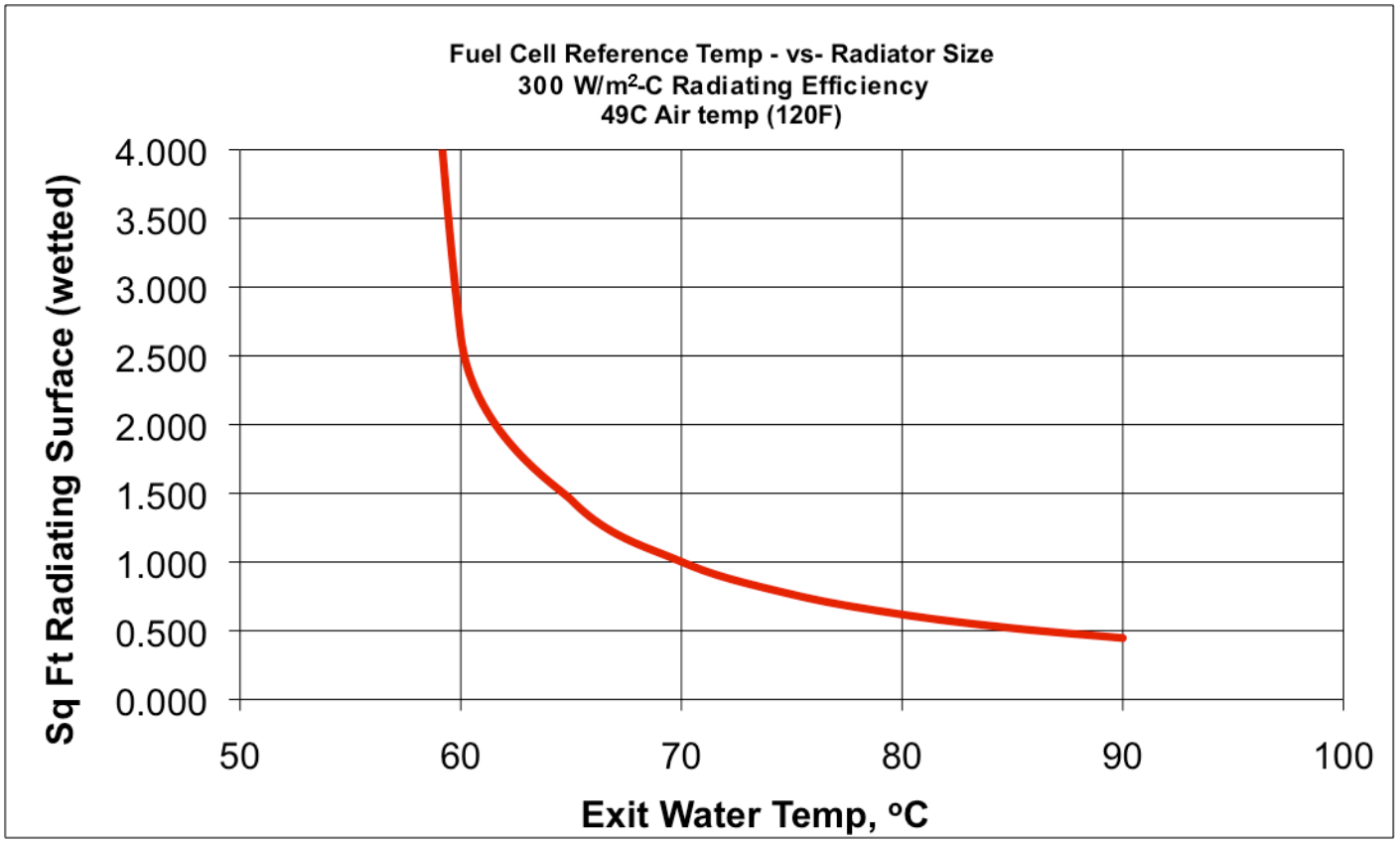
New components/features

- new humidifier design
- new air blower
- higher power stack
- integrated control electronics
- 99% H_2 utilization

POWERED BY Protonex

Ion Tiger Radiator Cooling System
120 °F/49 °C ambient operation

At start of program, fuel cell could not operate above 60 °C
Requires 7x larger radiator vs fuel cell that operates at 80 °C



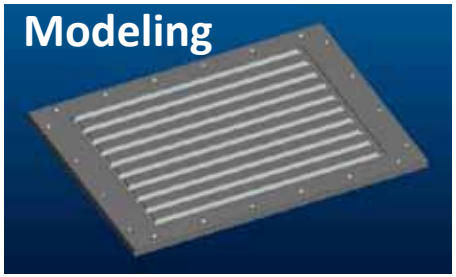
Solution: Protonex incorporated new fuel cell membranes with higher temperature capability

Ion Tiger Radiator Cooling System

New radiator enables Ion Tiger operation in 120°F environment

✓ **Developed analytical tools for future designs/improvements**

Spider Lion Radiator



Operation in warmer environments

Enabled by technical solutions:

- Lightweight radiator with improved heat transfer
- Higher fuel cell temperature with robust humidifier design and stack membranes

Solutions came from:

- Thermal modeling of fuel cell and radiator
- Wind tunnel testing of radiator designs
- Improved radiator fabrication expertise

Hydrogen as a Fuel

HIGH ENERGY FUEL

- Energy/weight: ~ 4600 Wh/kg
- Up to 10,000 psi gas in development
  - 5000 psi best weight advantage for UAVs
- International path for fuel cell automobiles

ADVANTAGES

- Responds immediately to change in load
- No waste produced (only H_2O)
- Produced and monitored onboard naval platforms

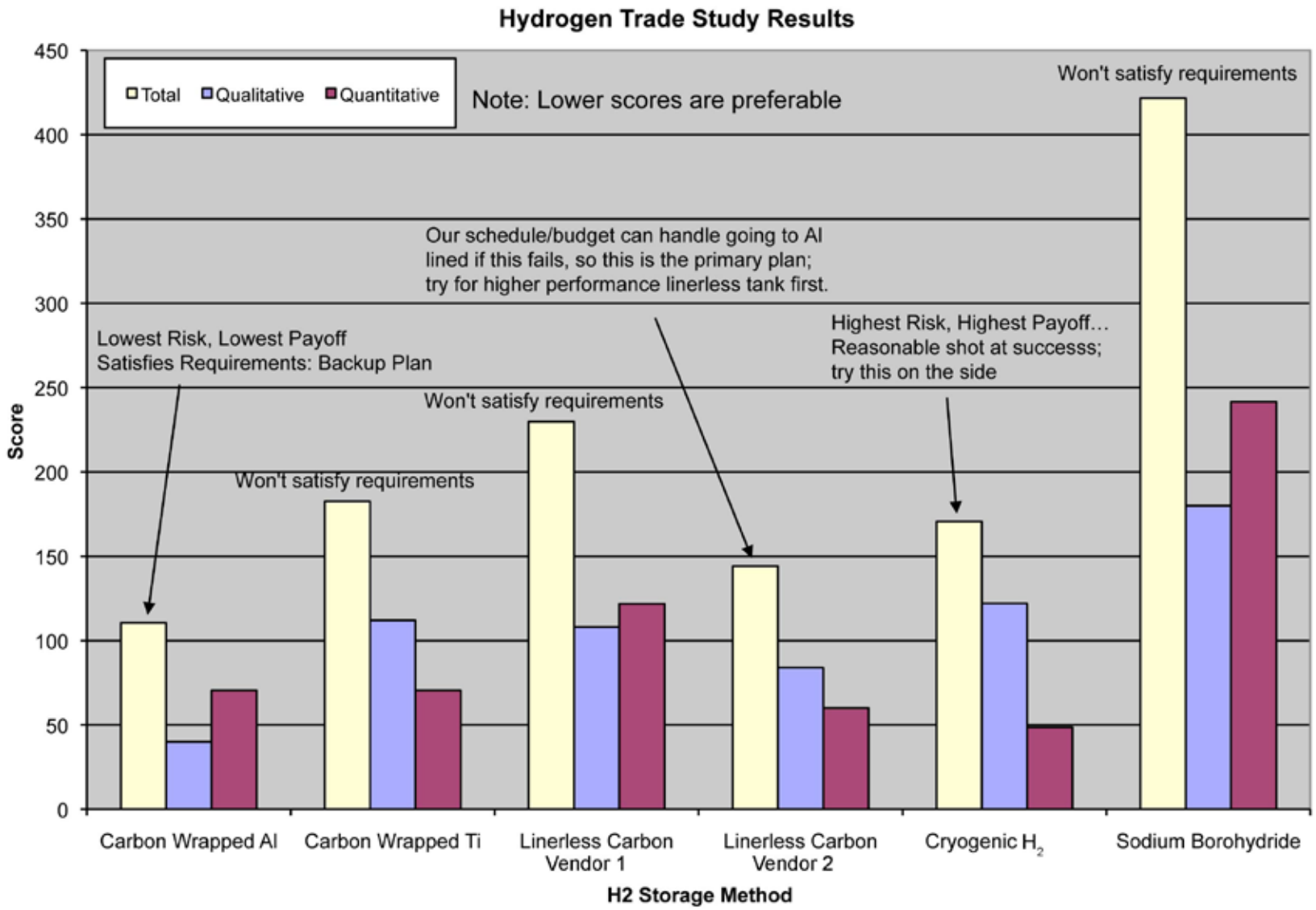
DISDAVANTAGES

- Difficult logistics for remote land locations
- Large storage volume (but OK for UAVs)

Liquid hydrogen fueling system being deployed for Global Observer

LH_2 is 3X as dense as gas!

Ion Tiger Hydrogen Storage Trade Study



Carbon Overwrapped Aluminum H_2 Tanks

New technologies demonstrated:
* Metal spinning for custom tanks sizes
* Demonstrated new resins with 10% more strength

22-liter tank made by metal spinning

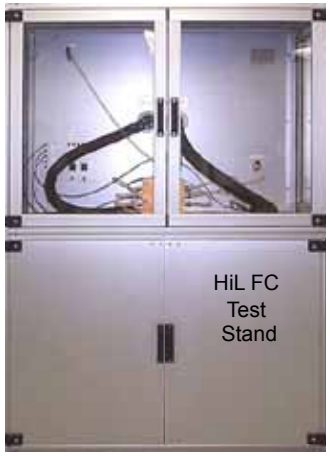
Carbon Overwrapped Pressure Vessel

Integrated into the Ion Tiger

Achieved program goal of 500 g hydrogen storage in 22-L tank weighing 3.6 kg (8 lbs) including 0.15 kg regulator = **13% H_2 storage**

Hawaii-ONR Fuel Cell Test Facility

Facility View



HiL & GLP Test Stand

Leverage Fuel Cell Test Facility at Hawaii Natural Energy Institute

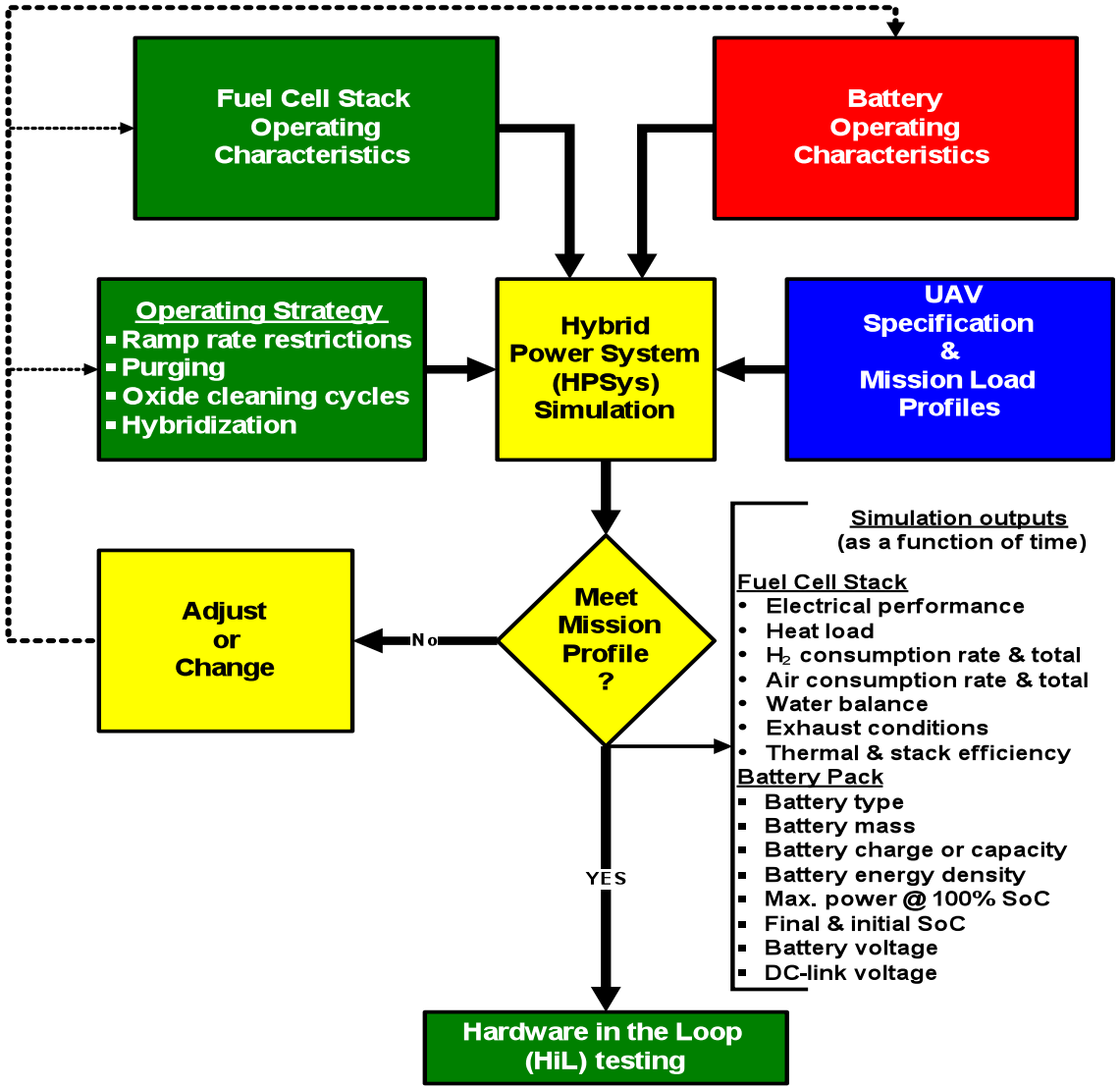
Tasks:

1. Map out full performance matrix of fuel cell stacks
2. Optimize components with hardware-in-loop (HiL)

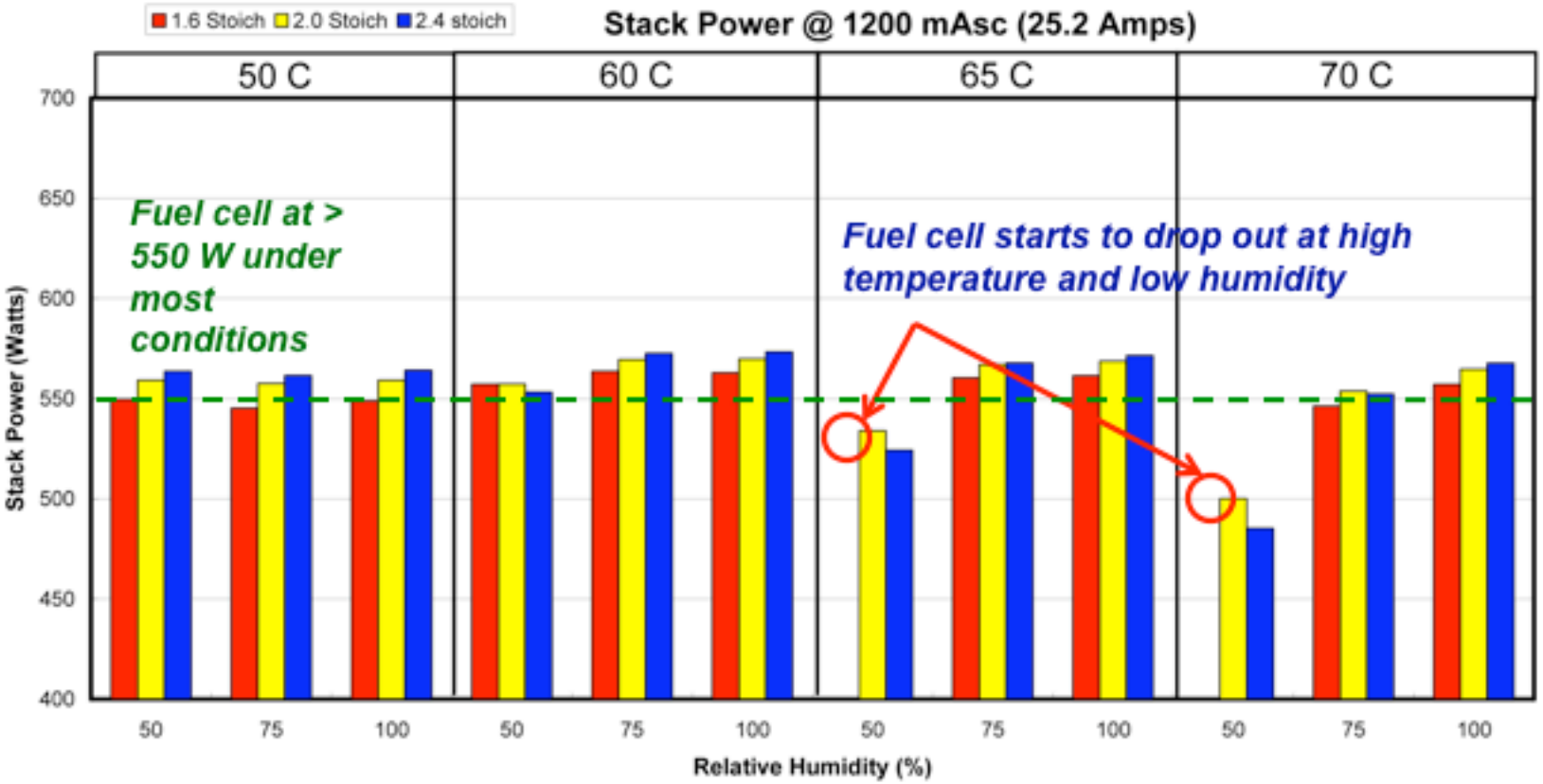
- 11 Test Stands
  - Single cells (25 to 600 cm^2)
  - Stacks up to 2 kW
  - Hardware-in-the-Loop (HiL) dynamic testing of cell and stacks
- On-site production of high purity hydrogen and air
- High resolution on-line gas analysis
- 24/7 automated operation with secure on-line data access
- US Fuel Cell Council and industry validated test protocols
- Full-time trained test engineers

Hawaii Natural Energy Institute
www.hnei.hawaii.edu

Hardware in Loop Set Up



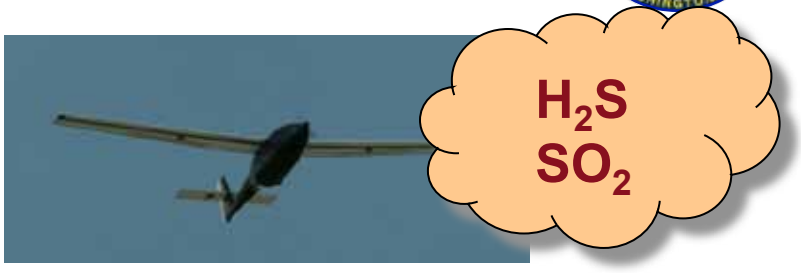
Fuel cell testing at HNEI

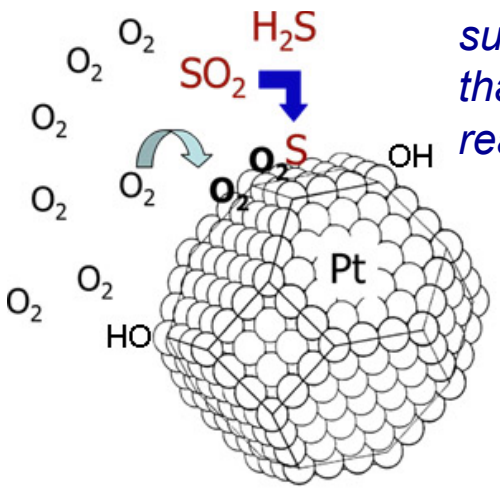


Map out stack performance vs: temperature; humidity; current density; air to gas stoichiometry

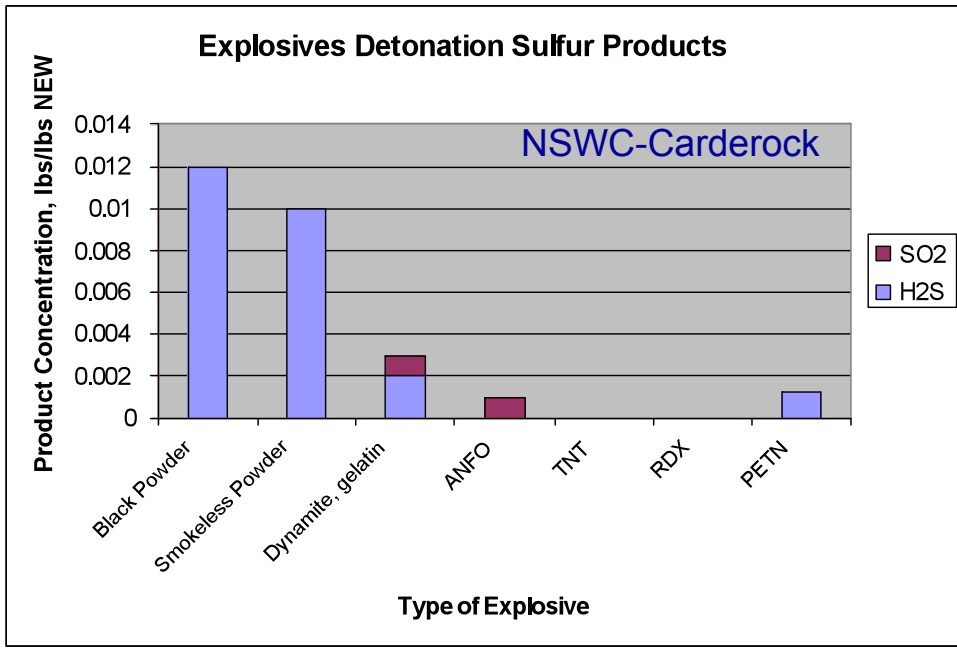
Fuel cell survivability in naval environments

- Motivation: Develop methods to regain power *during operation and maintenance* if catalysts are poisoned.
  - Sulfur in air can poison cathode catalysts
  - Electrode performance can be regained under certain cycling conditions

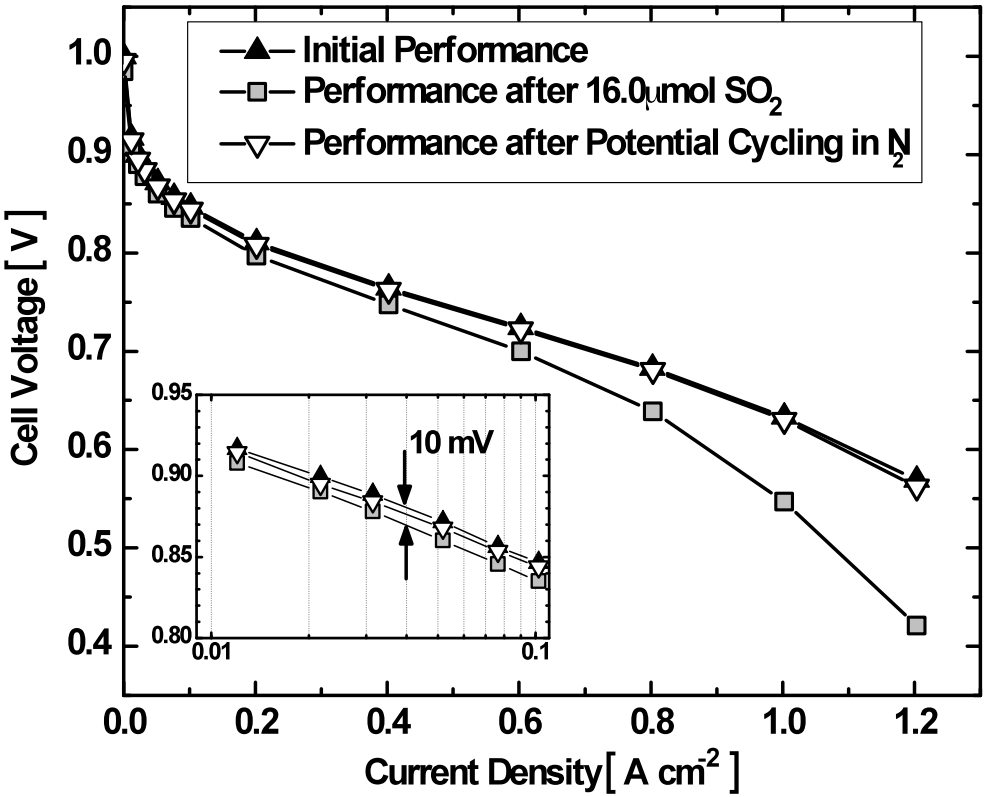




Sulfur blocks surface of Pt so that O_2 cannot react



New method developed to recover sulfur-poisoned fuel cell



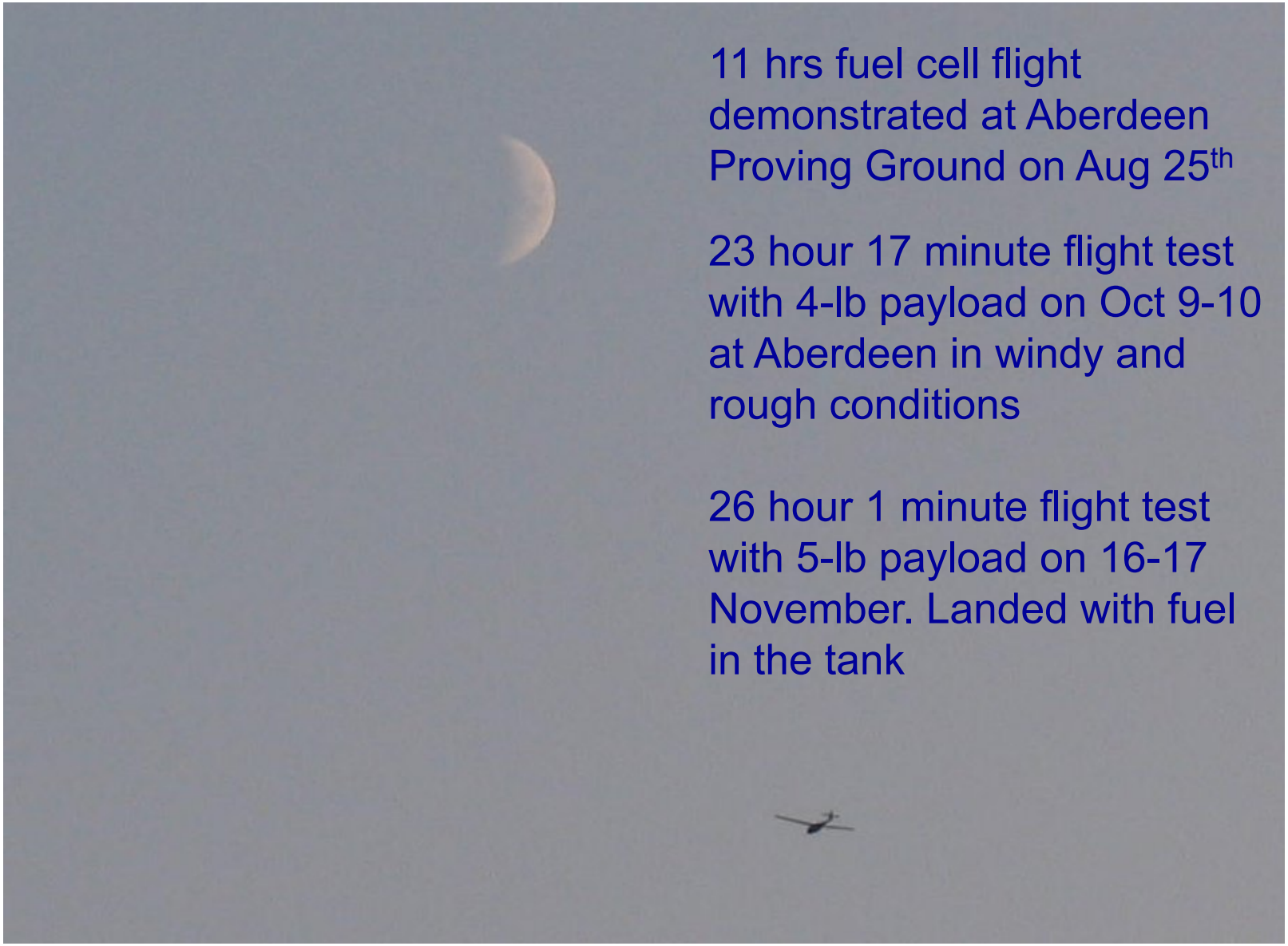
New method demonstrated to recover fuel cell performance in less than one minute

- ✓ *Cycle electrode to high potential (1.1 V) to oxidize sulfur to sulfate*
- ✓ *Desorb the sulfate at low potentials (<0.2 V)*

The result of several years of research ….

Fuel cell performance can be recovered during flight if the fuel cell is contaminated

Flight testing

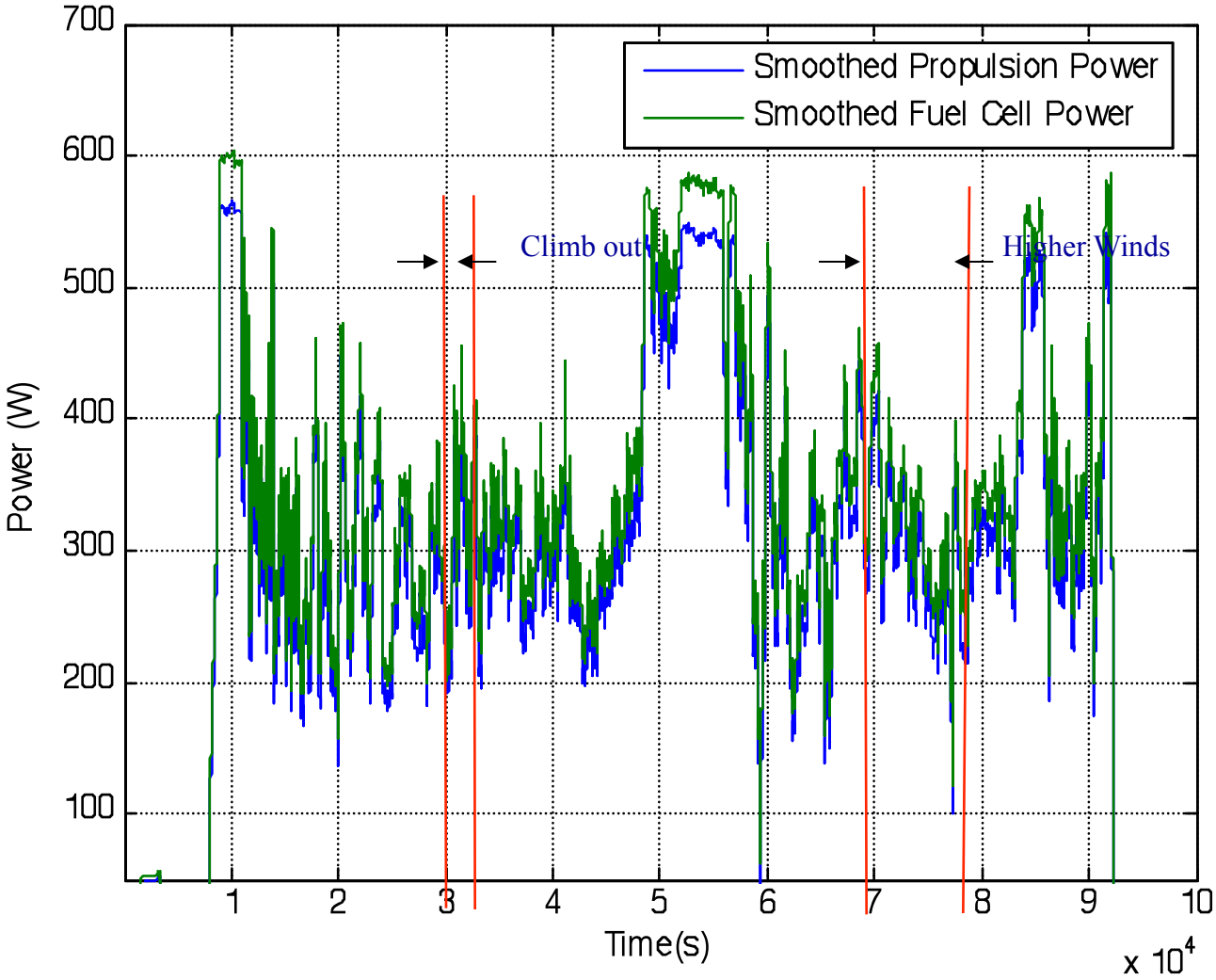


11 hrs fuel cell flight demonstrated at Aberdeen Proving Ground on Aug 25th

23 hour 17 minute flight test with 4-lb payload on Oct 9-10 at Aberdeen in windy and rough conditions

26 hour 1 minute flight test with 5-lb payload on 16-17 November. Landed with fuel in the tank

Power profile for 23 hr flight



Cold front from 2 to 4 AM
Vehicle flew at full power for >20% of flight
Hybridization with battery inadequate

System level considerations

1.Ion Tiger system grew in complexity over the course of the program

2.“Hybridization” will not work for naval platforms

- The 11- and 23- hour flights had periods when fuel cell used at full power for long periods of time
  - *Maximum power of fuel cell is maximum power of system*
- May be an opportunity for load leveling if we can get small high power batteries

FY10 Ion Tiger Plans

- Increase in fuel cell power from 550W to 1.5 kW (2 HP)
  - Protonex Technology Corp under contract to build breadboard system
- Demonstrate 3-day flight of Ion Tiger with cryogenic hydrogen
  - Store 3x more fuel for same weight as compressed hydrogen
  - Goal to fly in Fall 2010

Summary and Outlook

Ion Tiger program has been successful.

- Completed 26+ hour flight in windy conditions.
- 24 h flight with a 5 lb payload in sight

Success owed to:

- High performance fuel cell
- Improved radiators/thermal strategy
- Lightweight hydrogen storage

Other enabling technologies

- Thermal model
- Improved fuel cell components
- Fuel cell system model
- Method for recovery of poisoned fuel cells

NRL Progress in Fuel Cell Propulsion Systems